Optimization of Process Parameters for Car Side Mirror Using Taguchi Method and Artificial Neural Network

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Abstract

Injection molding is a appropriate process for complex geometry products with a single production step. However, to minimize deflection of product such as warpage by choosing optimal parameters is difficulty. By using CAE software, simulation of injection process was conducted to describe the response for product with various input parameters. After a series of simulation, optimal operated condition was analyzed by using statistics approach such as Taguchi method, ANOVA, Principal component analysis (PCA). In this study, a set of optimal processing parameters such as melting temperature, injection pressure, packing pressure and packing time will be used to determine the minimum warpage for car side mirror. A back propagation neural network and Taguchi method is proposed to optimize the injection process. This combination provides an advance technique to obtain the warpage result for further study.

Keywords: *warpage, injection molding, numerical simulation, Taguchi method, artificial neural network, CAD-CAE.*

Introduction

Plastic injection molding is the most suitable process to manufacture complex geometry and precise dimension parts in mass production. A part with desire shape is formed by a process of forcing melt polymer into a cold empty cavity and then allowed to solidify under holding pressure. Due to the temperature of plastic material undergoes and pressure increases, significant shear deformation during molding process, followed by rapid loss of temperature and pressure in the mold cavity, which leads to solidification, and locking of residual stress, orientation, and other part properties that determine the molded part quality.

Warpage is the most popular defect that affects critically on quality of plastic products, which is a distortion where the surfaces of the molded part do not follow the intended shape of the design. However, it is very complicated to achieve low and uniform shrinkage due to the presence and interaction of many factors such as molecular and/or fiber orientations, mold cooling, part and mold designs, and process conditions [1]. This kind of defects cannot totally be eliminated, but it can be minimize by optimizing the process parameter.

By using computer aid engineering (CAE) software in design and manufacturing process, the quality improvement and cost reduction can be impacted through the applications of various computer simulation techniques. In this study, Moldex3D is used to simulate injection process and describe the response warpage results. The optimal parameters of injection molding of side mirror can be predicted by comparing the pre-optimization results of Taguchi method and back propagation neural network.

Experiments

To proceed this study, the design of car side mirror first will be created by NX6.0. The designed part as shown in Fig.1 is imported into Moldex3D designer to build the mesh and also create cooling system, runner system, gate, sprue, cavity. Then, plastic material properties, condition, process parameters, machine will be simulated to get warpage results. The flow chart of experiment is shown in Fig.2.

The material used in this study is a commercial resin of acryonitrile butadiene styrene (ABS). Trade name, manufacturer, grade and other general specifications of this material are shown in Table 1.

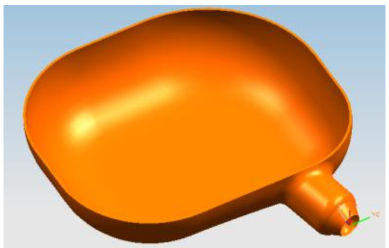

Fig 1. Mirror design in NX 6.0

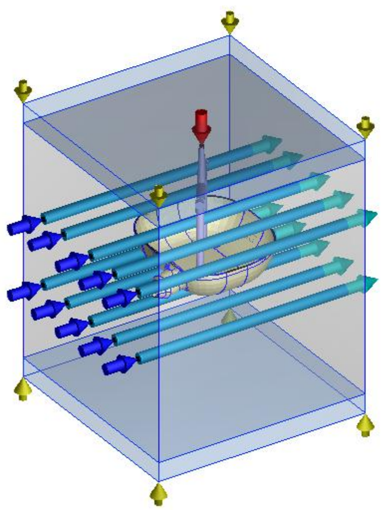

Fig 2. 3D model for injection molding analysis

Table 1. Properties of material

Material name	ABS
Catergory	Thermo plastic
Manufacturer	CHI MEI
Trade name	POLYLAC PA718
Element number	1185407
Part elements	1185407
Node number	723577

Pre-optimization by Taguchi method

Taguchi method developed by Taguchi consists of three stages which are system, parameters, and tolerance designs, respectively. By applying Taguchi method based on orthogonal arrays, time and cost required for conducting of the experiments can be reduced. Taguchi recommends the use of the S/N ratio for determination of the quality characteristics implemented in engineering design problems. The S/N ratio characteristics with signed-target type can be divided into three stages: the smaller is the better, the nominal is the best, and the larger is the better [2].

Three stages of factors are used to find out potential warpage included melt temperature (A), injection pressure (B), packing pressure (C) and packing time (D), as shown in Table 2. An L27 [3] orthogonal array table was conducted for this study. The layout of the L27 is given by Table 3.

Table 2. Injection parameters with three stages

Factors	Level		
	1	2	3
A: Melt temperature (^{o}C)	180	210	240
B: Injection pressure (MPa)	120	130	140
C: Packing Pressure(MPa)	130	140	150
D: Packing Time (s)	3	5	7

In determination of signal to noise ratios, the smaller the better quality characteristic has been selected.

$$\frac{S}{N} = -10log\left[\frac{1}{n}\sum_{i=1}^{n} y_i^2\right] \quad (1)$$

For the smaller the better, S/N where n is the number of warpage datasets (which equal to 27) and y_i is the warpage value for *ith* dataset. The best warpage result of 27 simulations is shown in Fig 3. The response table of S/N ratios is given by Table 4. In this table , the best set of combination parameters can be determined by selecting level with highest value for each factor. As a result, optimal process parameter combination for ABS is A1, B3, C1 and D1, as shown in Fig 4.

Due to the combination of optimal process conditions was not included in the experiments. Therefore, a confirmed experiment for the optimal conditions was proceeded to achieve the corresponding warpage of 0.4935 mm, shown in Table 6.

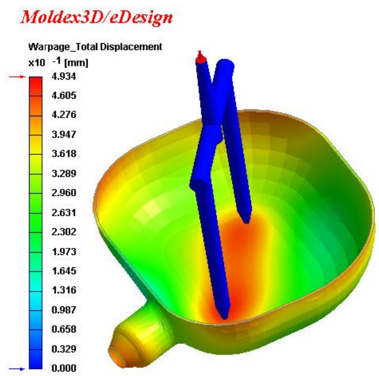

Fig 3. The best warpage result

Neural network training for warpage prediction

An artificial neural network (ANN) is a multilayered architecture composed of one or more hidden layers placed between the input and output layers. The layers include processing units known as neurons. They are connected with variable weights that must be determined.

A neuron in the network produces its output by processing the input through an activation function [4,5].

Table 3. L_{27} orthogonal array

No	A	B	C	D	Warpage (mm)	S/N (dB)
1	1	1	1	1	0.5074	-5.8930
2	1	2	2	2	0.5437	-5.2928
3	1	3	3	3	0.6111	-4.2748
4	1	1	1	2	0.5159	-5.7487
5	1	2	2	3	0.5293	-5.5260
6	1	3	3	1	0.5534	-5.1392
7	***1***	***1***	***1***	***3***	***0.4934***	***-6.1306***
8	1	2	2	1	0.5494	-5.2022
9	1	3	3	2	0.6166	-4.1999
10	2	2	3	1	0.7097	-2.9785
11	2	3	1	2	0.5698	-4.8856
12	2	1	2	3	0.6106	-4.2849
13	2	2	3	2	0.7048	-3.0387
14	2	3	1	3	0.5433	-5.9229
15	2	1	2	1	0.6423	-3.8452
16	2	2	3	3	0.6752	-3.4114
17	2	3	1	1	0.5729	-4.8384
18	2	1	2	2	0.6381	-3.9022
19	3	3	2	1	0.6258	-4.0713
20	3	1	3	2	0.7107	-3.0770
21	3	2	1	3	0.5489	-5.2101
22	3	3	2	2	0.6329	-3.9733
23	3	1	3	3	0.6837	-3.3027
24	3	2	1	1	0.5546	-5.1204
25	3	3	2	3	0.6154	-4.2169
26	3	1	3	1	0.6968	-3.1378
27	3	2	1	2	0.5631	-4.9883

Table 4. The response table of S/N ratios

Level	A	B	C	D
1	-5.2674	-4.3691	-5.4159	-4.4695
2	-4.1230	-4.5298	-4.4794	-4.3451
3	-4.1219	-4.6135	-3.6177	-4.3308

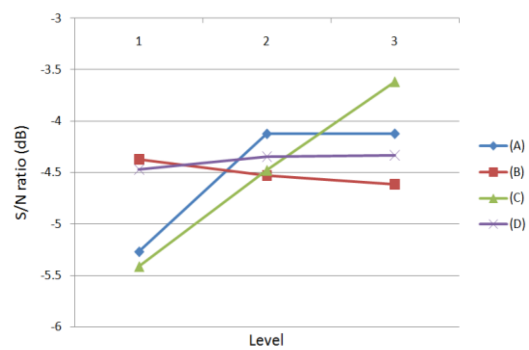

Fig 4. Effects of the parameters on the warpage

The activation (transfer) function, f(x), used in this study is *sigmoid* function

$$f(x) = \frac{1}{1 + exp^{(-x)}} \qquad (2)$$

In this study, ANN architecture consists of one input, two hidden and one output layers, as shown in Fig 4. The inputs were the melt temperature, mold temperature, packing pressure and packing time, while the output was warpage value of side mirror with ABS material, as shown in Fig 5. The network was trained by the Back propagation type in Matlab Neural Toolbox. A training data set of 24 simulations in Table

5 was used to train the network. And the rest were used for testing purpose. The training process was performed for 400,000 cycles. The momentum and learning rate was taken to be 0.9 and 0.1, respectively.

After 400,000 cycles, the mean square error (MSE) predicted by network is equal to 0.00001. The trained network was tested by 3 data sets that were not included in training process. And then the comparison of predicted by Moldex3D and ANN were shown in Table 5 with maximum error of 1.39%. Therefore, the ANN model is good for optimization process parameters.

In the Table 6, the optimal injection conditions were determined by comparing the predicted result and experimental warpage values.

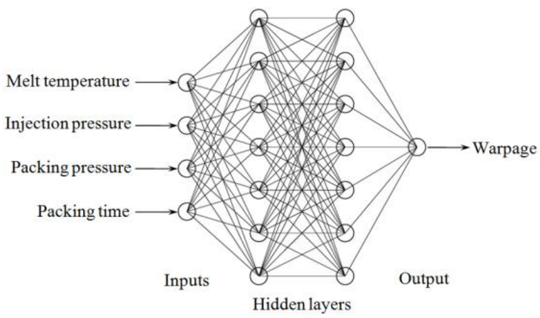

Fig 5. The architecture of the neural network predictor model

Table 5. Comparison of the test data set

No	Parameter				Warpage		
	A	B	C	D	Moldex	ANN	Error (%)
1	1	2	2	3	0.5293	0.5219	1.39
2	2	3	1	1	0.5729	0.5808	1.36
3	3	2	1	2	0.5631	0.5558	1.29

Table 6. Comparison of the warpage of the optimization result between Taguchi and ANN

	Optimal parameter value				Warpage (mm)
	A	B	C	D	
Taguchi	180	140	130	3	0.4935
ANN	180	140	130	3	0.5117

Discussion

In this study, L27 orthogonal array is appropriate to cover the optimization process with 4 parameters and 3 levels. The warpage results were distributed within range of 0.4934 mm to 0.7107 mm. The optimal process parameters were determined by highest S/N ratio for each factor , as shown in Fig 4.

The error between optimum warpage value predicted by ANN (0.5117 mm) and simulation result (0.4935). This error might be caused by the difference in training data for the ANN. However, this obtained error in training and testing process is acceptable. Therefore, both Taguchi and ANN can be considered suitable methods for the optimization process.

Conclusion

In this case study of car side mirror, Taguchi method were utilized to investigate the effects of the four factors on warpage of ABS. The approach of this method has shown the effectiveness in determining the optimal values of process parameter. ANN has proven to be a powerful technique that can replace the simulation software such as Moldex3D to predict warpage values. So that the efficiency of further study can be achieved more easily.

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